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14. ABSTRACT

The primary objective of this MURI research is to develop the theory and operation of heterogeneous sensor networks that can provide a desired quality of sensor fusion for creating actionable situation awareness. This goal is being achieved by developing (i) Mathematically rigorous and novel language theoretic sensor data representation and multi-level heterogeneous sensor fusion techniques that require substantially less sensing and communication resources as compared to conventional techniques, and (ii) Fusion-driven dynamic control and adaptation of heterogeneous sensor networks.

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ABSTRACT

The primary objective of this MURI research is to develop the theory and operation of heterogeneous sensor networks that can provide a desired quality of sensor fusion for creating actionable situation awareness. This goal is being achieved by developing (i) Mathematically rigorous and novel language theoretic sensor data representation and multi-level heterogeneous sensor fusion techniques that require substantially less sensing and communication resources as compared to conventional techniques, and (ii) Fusion-driven dynamic control and adaptation of heterogeneous sensor networks.

Individual sensors have limited computing, energy and communication resources, whereas the information processing required to extract actionable situation awareness from a network of such sensors is highly complex. These conflicts led us to design a novel sensor architecture that partitioned the overall design into two separate but interacting design spaces, (1) Information Space (IS): deals with all the information processing tasks, e.g., sensor data coding, compression and fusion, and (2) Network Design Space (NS): deals with all the sensor networking, communication and network control & adaptation tasks.

In addition to the theoretical research, our research also involves experimental validation of the individual theoretical research problems as well as integrated research. For this purpose, we have created a sensor network test bed consisting of a sensor network simulator integrated with real sensor nodes and real sensor networks. This test bed has been successfully used to test the Heterogeneous Dynamic Space Time Clustering (HDSTC) for target tracking. The HDSTC also integrates research ideas from all the MURI team members.

Major innovations of this year, outlined in following sections of this report, have been: (i) contextual semantic reasoning, learning and adaptation, making use of influence diagrams and dynamic decision networks; (ii) exploitation of cross-modal sensor dependencies; (iii) semantic fusion for upper layer control; and (iv) complete coverage of search area for a single robot.

The results of this research have led to formal techniques for multi-level fusion of heterogeneous sensor data and have furthered efforts to design engineered sensor networks whose structure is simultaneously adaptive, near optimal and resilient to events caused by either the sensed environment or the inherent network behaviors. The outcomes of this research when incorporated into real DoD sensor systems will lead to systems capable of robust context-adaptive and dependable surveillance with minimal human dependence.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

<u>Received</u>   <u>Paper</u>

05/19/2014 54.00 Xin Jin, Asok Ray. Navigation of autonomous vehicles for oil spill cleaning in dynamic and uncertain environments,
International Journal of Control, (04 2014): 787. doi: 10.1080/00207179.2013.858829

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TOTAL: **39**

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

<u>Received</u>   <u>Paper</u>

07/03/2013 46.00 Pankaj K. Agarwal, Siu-Wing Cheng, Ke YI. Range Searching on Uncertain Data,
ACM Transactions on Algorithms, (08 2012): 0. doi:

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Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

<u>Received</u>   <u>Paper</u>

07/29/2011 60.00 Pankaj K. Agarwal, Graham Cormode , Zengfeng Huang, Jeff M. Phillips, Zheiwei Wei, Ke Yi. Mergeable
Summaries,
Third Workshop on Massive Data Algorithmics (MASSIVE), 2011. , . : ,

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Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

<u>Received</u>   <u>Paper</u>

05/19/2014 53.00 Pankaj K. Agarwal, Swaminathan Sankararaman, Thomas Mølhave, Jiangwei Pan, Arnold P. Boedihardjo. Model-driven matching and segmentation of trajectories,
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07/23/2012 98.00 Atilla Eryilmaz, Ness B. Shroff, Wenzhuo Ouyang. Low-complexity Optimal Scheduling over Correlated Fading Channels with ARQ Feedback,
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07/24/2012 02.00 Pankaj K. Agarwal, Graham Cormode, Zengfeng Huang, Jeff Phillips, Zhewei Wei, Ke Yi. Mergeable summaries,
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08/07/2012 17.00 Shalabh Gupta , Jacqueline M. Luff , Asok Ray, Xin Jin . Multi-Resolution Navigation of Mobile Robots with Complete Coverage of Unknown and Complex Environments,
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IEEE INFOCOM 2011 - IEEE Conference on Computer Communications. 10-APR-11, Shanghai, China. : ,

08/11/2011 42.00 Soumik Sarkar, Dheeraj S. Singh, Abhishek Srivastav, Asok Ray. Semantic Sensor Fusion for Fault Diagnosis in Aircraft Gas Turbine Engines,
2011 American Control Conference. 29-JUN-10, . : ,

08/11/2011 44.00 Abhishek Srivastav, Yicheng Wen, Evan Hendrick, Ishanu Chattopadhyay, Asok Ray, Shashi Phoha, . Information Fusion for Object & Situation Assessment in Sensor Networks,
2011 American Control Conference. 29-JUN-11, . : ,

08/11/2011 47.00 Patrick Adenis, Kushal Mukherjee, Asok Ray. State Splitting and State Merging in Probabilistic Finite State Automata,
2011 American Control Conference. 01-JUL-11, . : ,

08/11/2011 48.00 Xin Jin, Shalabh Gupta, Asok Ray, Thyagaraju Damarla. Symbolic Dynamic Filtering of Seismic Sensors for Target Detection and Classification,
2011 American Control Conference. 01-JUL-11, . : ,

08/11/2011 63.00 Srikanth Hariharan, Chatschik Bisdikian, Lance M. Kaplan, Tien Pham. QoI-based Resource Allocation for Multi-Target Tracking in Energy Constrained Sensor Networks,
IEEE Fusion, July 2011. 05-JUL-11, . : ,

08/11/2011 64.00 Behetash Babadi, Vahid Tarokh. Regularized Recursive Least Squares for Anomaly Detection in Sparse Channel Tracking Applications,
9th Annual IEEE Consumer Communications and Networking Conference (CCNC'11). 02-NOV-11, . : ,

08/11/2011 66.00 Alex Beutel, Thomas Mølhave, Pankaj K. Agarwal, Arnold P. Boedihardjo, James A. Shine. Natural Neighbor Interpolation on a 3D Grid using a GPU,
19th SIGSPATIAL International Conference on Advances in Geographic Information Systems (ACM GIS ' 11). 01-NOV-11, . : ,

08/14/2012 05.00 Pankaj K. Agarwal, Jun Yang, Albert Yu. Processing and Notifying Range Top-k Subscriptions,
2012 IEEE International Conference on Data Engineering (ICDE 2012). 01-APR-12, Arlington, VA, USA. : ,

TOTAL: **59**

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received	Paper

07/18/2013 47.00   Soheil Bahrampour, Asok Ray, Soumalya Sarkar, Thyagaraju Damarla, Nasser M. Nasrabadi. Performance Comparison of Feature Extraction Algorithms for Target Detection and Classification, Pattern Recognition Letters (07 2013)

07/23/2012 92.00   Zhoujia Mao, Can Emre Koksal, Ness B. Shroff. Near Optimal Power and Rate Control of Multi-Hop Sensor Networks With Energy Replenishment: Basic Limitations With Finite Energy and Data Storage, IEEE Transactions on Automatic Control (04 2012)

07/23/2012 85.00   Patrick Adenis, Yicheng Wen, Asok Ray. An inner product space on irreducible and synchronizable probabilistic finite state automata, Mathematics of Control Signals and Systems (01 2012)

07/23/2012 88.00   G. Mallapragada, A. Ray, Xin Jin. Symbolic Dynamic Filtering and Language Measure for Behavior Identification of Mobile Robots, IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics) (06 2012)

07/23/2012 89.00   Xin Jin, Soumalya Sarkar, Asok Ray, Shalabh Gupta, Thyagaraju Damarla. Target Detection and Classification Using Seismic and PIR Sensors, IEEE Sensors Journal (06 2012)

07/23/2012 86.00   Soumik Sarkar, Kushal Mukherjee, Xin Jin, Dheeraj S. Singh, Asok Ray. Optimization of symbolic feature extraction for pattern classification, Signal Processing (03 2012)

07/23/2012 87.00   Devesh K. Jha, Dheeraj S. Singh, S. Gupta, A. Ray. Fractal analysis of crack initiation in polycrystalline alloys using surface interferometry, EPL (Europhysics Letters) (05 2012)

07/23/2012 90.00   Soumik Sarkar, Kushal Mukherjee, Asok Ray, Abhishek Srivastav, Thomas A. Wettergren. Statistical Mechanics-Inspired Modeling of Heterogeneous Packet Transmission in Communication Networks, IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics) (08 2012)

07/23/2012 91.00   Asok Ray, Kushal Mukherjee, Subhadeep Chakraborty, Devesh K. Jha. Classification of Two-phase Flow Patternsby Ultrasonic Sensing*, Journal of Dynamic Systems Measurement and Control (12 2011)

07/24/2012 00.00   Pankaj K. Agarwal, Peyman Afshani, Lars Arge, Kasper Green Larsen, Jeff M. Phillips. (Approximate) Uncertain Skylines, Theory of Computing Systems (02 2012)

07/27/2012 94.00   Vahid Tarokh, Behtash Babadi. Distributed Dynamic Spectrum Allocation for Secondary Users in a Vertical Spectrum Sharing Scenario, IEICE TRANSACTIONS on Communications Vol.E95-B No.4 pp.1044-1055 (04 2012)

08/07/2012 14.00   Yicheng Wen, Asok Ray. Vector space formulation of probabilistic finite state automata, Journal of Computer and System Sciences (07 2012)

08/14/2012 93.00   Jiho Ryu, Changhee Joo, Ted "Taekyoung" Kwon, Ness B. Shroff, Yanghee Choi. DSS: Distributed SINR based Scheduling Algorithm for Multi-hop Wireless Networks, IEEE Transactions on Mobile Computing (04 2012)

TOTAL: **13**

Books

Received   Book

08/11/2011 81.00 Shashi Phoha, Doina Bein, Yicheng Wen, Bharat B. Madan, Asok Ray. Dynamically Adaptive Multi-modal Sensor Fusion in Urban Environments, : , (08 2011)

08/11/2011 82.00 Behtash Babadi, Doina Bein, Bharat B. Madan, Shashi Phoha, Vahid Tarokh, Yicheng Wen. Improving Target Localization and Tracking by Dynamically Prioritized Frequency Band Allocation for Wireless Sensor Networks in Urban Environments, : , (12 2011)

08/22/2012 23.00 Xin Jin, Shalabh Gupta, Kushal Mukherjee, Asok Ray. Symbolic Dynamic Filtering for Pattern Recognition in Distributed Sensor Networks, Boca Raton, Florida: Chapmam & Hall / CRC, (09 2012)

    TOTAL: **3**

Received   Book Chapter

    TOTAL:

Patents Submitted

Patents Awarded

Awards

2008
Dr. Ness Shroff recipient of the best paper award for IEEE INFOCOM 2008.

Dr. Pankaj K. Agarwal: R.J.R. Nabisco Professor of Computer Science and Mathematics.

2009
Best Paper Presentation in the Session by S. Sarkar, Graduate Student S. Sarkar, C. Rao and A. Ray, "Estimation of Multiple Faults in Aircraft Gas-turbine Engines," American Control Conference, St. Louis, MO, June 2009.

Best Paper Presentation in the Session by S. Sarkar, Graduate Student S. Sarkar, K. Mukherjee, A. Srivastav and A. Ray, "Understanding phase transition in communication networks to enable robust and resilient control," American Control Conference, St. Louis, MO, June 2009.

Best Paper Presentation in the Session by Dr. I. Chattopadhyay, Research Associate I. Chattopadhyay and A. Ray, "Generalization of v* Path Planning For Accommodation of Amortized Dynamic Uncertainties in Plan Execution," American Control Conference, St. Louis, MO, June 2009

Best Paper Presentation in the Session by Dr. I. Chattopadhyay, Research Associate I. Chattopadhyay and A. Ray, "Supervised Self-organization of Large Homogeneous Swarms Using Ergodic Projections of Markov Chains," American Control Conference, St. Louis, MO, June 2009.

Best Paper Presentation in the Session by Dr. I. Chattopadhyay, Research Associate W. Lu, I. Chattopadhyay, G. Mallapragada and A. Ray, "A Real time Implementable All-Pair Dynamic Planning Algorithm for Robot Navigation Based on the Renormalized Measure of Probabilistic Regular Languages," American Control Conference, St. Louis, MO, June 2009.

Dr. Ness Shroff Guest Chaired Professor of Wireless Communications and Networking, Dept. of Electronic Engineering, Tsinghua University, Beijing, China (April 2009 - April 2012).
Dr. Ness Shroff Distinguished Invited Speaker, IEEE 17TH International Conference on Computer Communication and Networks (ICCCN), Aug. 2008.

Dr. Ness Shroff Invited Panel member on "What are the hot topics in Networking?" IEEE INFOCOM 2009, April 2009, Rio De Janiero, Brazil.
Dr. Ness Shroff Invited Panel member on "Future of Multi-hopping: from Theory to Practice," ACM Mobihoc 2009, May, New Orleans.

Dr. Pankaj K. Agarwal Best paper award: Efficient sensor placement for surveillance problems, in Fifth IEEE International Conference on Distributed Computing in Sensor Systems, 2009.

Dr. Roger Brockett recipient of the 2009 IEEE Leon Kirchmeyer Award for Graduate Education.
Alan O'Connor won the "Zhang Si-Ying (CCDC) Outstanding Youth Paper Award", for his paper at the 21st Chinese Control and Decision Conference.

2010
Behtash Babadi won the GSAS Fellowship Award, which is "awarded to one Phd student in each department for outstanding academic performance".

Ness Shroff:Keynote address on " Analytical Foundations for the Efficient, Robust, and Scalable Design of Multi-hop Wireless Networks, " MSN 2009, Yu Wi Mountain, China, December 2010.

Ness Shroff:Chaired Professor (Guest), Dept. of Electronic Engineering, Tsinghua University, Beijing, China 2009-2012.
Distinguished Seminar Speaker, Illinois Institute of Technology, April 2010.

Pankaj Agarwal:Amar S. Gupta Distinguished Professor, IIT Delhi, India

2011
Pankaj K. Agarwal, Best paper award "Natural Neighbor Interpolation Based Grid DEM Construction Using a GPU," Nineteenth ACM Symposium on Advances in Geographic Information Systems, 2010.

Ness B. Shroff, Keynote Address, "Beyond Stability: Open Problems in Multi-hop Wireless Networks," IEEE WiOPT 2011, Princeton, New Jersey, May 2011.

Roger Brockett, McDonald Mentoring Award

Vahid Tarokh, Guggenheim Fellowship

Behtash Babadi, Harvard University Graduate School of Arts and Sciences Fellowship Award

2012
Asok Ray won the 2012 Henry M. Paynter Outstanding Investigator Award
Vahid Tarokh won the 2012 IEEE COMSOC TCCN (Technical Committee of Cognitive Networks) Publication award.

X. Jin , S. Sarkar, A. Ray, S. Gupta, and T. Damarla, "Target Detection and Classification Using Seismic and PIR Sensors", IEEE Sensors Journal, Vol. 12, No. 6, June 2012, top 25 most downloaded Sensors Journal papers in the month of May, 2012

Best student paper award for the paper "Low-complexity Optimal Scheduling Over Correlated Fading Channels with ARQ Feedback," by W. Ouyang, A. Eryilmaz, N. B. Shroff, IEEE 10th International Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOPT'12), Paderborn, Germany, May 2012.

The paper "Mergeable summaries," by P. K. Agarwal, G. Cormode, Z. Huang, J. M. Phillips, Z. Wei, and K. Yi, in Proceedings 31st Annual Symposium on Principles of Database Systems, 2012, 23-34 was invited to the special issue of the conference.

Best paper presentation in American Control Conference, Montreal, Canada by Dr. Kushal Mukherjee (Postdoctoral Scholar)
Best paper presentation in American Control Conference, Montreal, Canada by Mr. Soumalya Sarkar (Graduate Student)

2013
Vahid Tarokh won the 2013 IEEE Eric E. Sumner Award

Ness Shroff won runner-up paper award at IEEE INFOCOM 2013 (1 best paper and 2 runner up papers were selected out of 1600 submitted papers)

Ness Shroff Honorary Guest chaired professor at Shanghai Jiaotong University in China, 2012

Shengbo Chen (OSU) Best student paper award at IEEE WiOPT, May 2013.

Pankaj Agarwal receiving honorary PhD Degree at Aarhus University, Denmark

Roger Brockett was named a Fellow of the American Mathematical Society

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Graduate Students

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Student Metrics
This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

Note that the lists provided for subcontracts and supported faculty, post-docs and students refer to the MURI's last year only. For complete lists covering the six-year MURI program, please refer to previous reports. Also attached is a list covering all student, faculty and staff associated with the project over the project years.

Last year's scientific and technical progress can be summarized by the following, most recent publications. The full extent of the scientific contribution including a complete list of publications over the course of the six-year MURI program can also be found in previous reports.

Peer-Reviewed Conference Proceeding publications (other than abstracts):
Pankaj K. Agarwal, Swaminathan Sankararaman, Thomas Mølhave, Jiangwei Pan, Arnold P. Boedihardjo. Model-driven matching and segmentation of trajectories, the 21st ACM SIGSPATIAL International Conference. 05-NOV-13, Orlando, Florida.

Papers published in peer-reviewed journals:
Siddharth Sonti, Eric Keller, Joseph Horn, Asok Ray. Stability Monitoring of Rotorcraft Systems: A Dynamic Data-Driven Approach, Journal of Dynamic Systems, Measurement, and Control, (01 2014): 0. doi: 10.1115/1.4025988

Kushal Mukherjee, Asok Ray. State splitting and merging in probabilistic finite state automata for signal representation and analysis, Signal Processing, (11 2014): 105. doi: 10.1016/j.sigpro.2014.03.045

Xin Jin, Asok Ray. Navigation of autonomous vehicles for oil spill cleaning in dynamic and uncertain environments, International Journal of Control, (04 2014): 787. doi: 10.1080/00207179.2013.858829

Technology Transfer

Technology has been transitioned to DoD projects, NASA and Industry.
The transitioning of technology developed in the past years into new areas and into products of relevance to DoD applications, while still producing relevant theoretical results in wireless sensor network communication and large sensor data management. Technology transition:
• Hierarchical sensor data fusion: we have proposed the use of a sequential decision tree for a multi-agent hybrid dynamic system and demonstrated the superiority of Nonlinear Symbolic Dynamic Filtering (SDF) algorithms for hierarchical sensor data fusion, using data collected in Army Research Lab/DHS experiments with static seismic and PIR sensors.
• Transferring the technologies of contextual and value based fusion from the MURI: We started working on a prototyped unmanned sensor system that will use the transformative advances in computational modeling, instrumentation and control developed in the MURI to incorporate a Dynamic Data Driven Adaptation (DDDA) of a complex distributed sensor system. The recent grant from AFOSR,
"Dynamic Data Driven Machine Perception and Learning for Border Control" will bring in the following major innovations to current state-of-the-art: (i) DDDA via embedded software agents who make sensor network control, adaptation and collaboration decisions based on the contextual information value of the competing data provided by different multi-modal sensors, (ii) DDDA of higher levels of the sensor data fusion framework using dynamic adaptation decisions made by the software agents, (iii) Unsupervised and supervised machine learning, reinforcement learning and transfer learning techniques to acquire and reuse knowledge for dealing with different operational contexts, and (iv) Use of robust sensor data fusion algorithms based on the SDF framework that have already been developed as part of our ongoing MURI research.
• Another strand of applications of the fundamental research on computational mechanics in this MURI is in fault detection and crack analysis on aircraft engines. The data-driven fault detection problem is posed as a multiclass pattern classification problem and an optimal solution has been proposed by partitioning the received sensor data in the SDF-based feature extraction setting, while dealing with sensor degradation (e.g., drift and noise).

Publication Numbers per Submitted Report year *	
2008:	
Published in Peer-Reviewed journals:	25
Non Peer-Reviewed Conference:	3
Published in Peer-Reviewed conference:	23
Books:	1
2009:	
Published in Peer-Reviewed journals:	28
Published in Peer-Reviewed conference:	27
Manuscripts:	5
2010:	
Published in Peer-Reviewed journals:	15
Published in Peer-Reviewed conference:	31
Manuscripts:	3
Books:	3
2011:	
Published in Peer-Reviewed journals:	20
Published in Peer-Reviewed conference:	30
Non Peer-Reviewed Conference:	1
Books:	2

*All other publications since 2011 are listed on the current report and generated by the database.

PATENTS SUBMITTED

1. Online monitoring of refractory wall damage in entrained bed slagging gasification systems (Dr. Ray, PSU)
2. Online void fraction measurement in two phase flow systems via nonlinear filtering of ultrasonic signals (Dr. Ray, PSU)
3. Diagnosis and Estimation of Multiple Faults in Aircraft Gas Turbine Engines (Dr. Ray, PSU)
4. Real time Fatigue Damage Monitoring and Remaining Life Estimation via In Situ Ultrasonic Sensing (Dr. Ray, PSU)

Graduate Students	Faculty	Other Research Staff
Amit Patel	Shalabh Gupta	Jason Douglas
Alan O'Connor	Changhee Joo	Kevin Fisher
Srikanth Hariharan	Ishanu Chattopadhyay	Pamela Beranty
Bo Ji	Doina Bein	Eric Grele
Jeff Phillips	Vahid Tarokh	John Koch
Shashidhara Ganjugunte	John Sustersic	
Sugumar Murugesan	Pankaj Agarwal	**PHDs awarded**
Subhadeep Chakraborty	Asok Ray	Yicheng Wen
Xin Jin	Ness Shroff	Abhishek Srivastav
Patrick Adenis	Bharat Madan	Sang Joon Kim
Evan J Hendrick	Shashi Phoha	Subhadeep Chakraborty
Chinmay Rao	Roger Brockett	Goutham Mallapragada
Soumalya Sarkar		Aparna Subbu
Devesh Jha	**Post Doctorates**	Dheeraj Singh
Michael Ferster	Xudong Chen	Xudong Chen
Xudong Chen	Junichiro Fukuyama	Seunghoon Nam
Omar Shammas	Amar Rasheed	Shashidhar Ganjungunte
Seunghoon Nam	Michael Moore	Chinmay Rao
Hong Tao Wu	Sarah Rajtmajer	Alan O'Connor
Shane Marcks	Eric Keller	Soumik Sarkar
Raghvendra Sharathkumar	Kushal Mukherjee	Srikanth Hariharan
Nurali Virani	Abhishek Srivastav	Kushal Mukherjee
Pritthi Chattopadhyah	Natasha deVroye	Behtash Babadi
Manish Gupta	Mai Vu	
Albert Yu	Esther Ezra	
Shengbo Chen	Shalabh Gupta	**Masters Awarded**
Sang Joon Kim	Ishanu Chattopadhyay	Steven Brown
Behtash Babadi		Soumik Sarkar
Matthew Cuppett	**Under Graduates**	Dheeraj Singh
Anthony Cascone	Andrew Homich	Jeff Phillips
Abhishek Srivastav	Dennis Kriczky	Kushal Mukherjee
Soumik Sarkar	Philip Swaney	Xin Jin
Kushal Mukherjee	Anna Rish	Patrick Adenis
Yicheng Wen	Zachary Kehs	Amit Patel
Goutham Mallapragada	Mathew Jones	Evan Hendrick
Zhoujia Mao	Andrew Harris	Michael Ferster
Ji Woo Kim	Brandon Tricou	Omar Shammas
Casey Trail	Scott Rager	
Sashidhar Gujgunte		